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MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS, MILLICAN RESERVOIR, NAVASOTA RIVER, LOWER BRAZOS RIVER SYSTEM, TEXAS

Public Health Service
Dallas, Texas

July 1960

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MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS

MILLICAN RESERVOIR

NAVASOTA RIVER

LOWER BRAZOS RIVER SYSTEM

TEXAS

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VII
Dallas, Texas

In Cooperation with the

DEPARTMENT OF THE ARMY
U. S. Army Engineer District - Fort Worth, Texas

JULY 1960

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INTRODUCTION

Authority

In a letter dated June 8, 1959, the District Engineer, Fort Worth District, Corps of Engineers, requested the Region VII Office, Public Health Service, to:

1. Recommend prospective needs for municipal and industrial water supply which might be satisfied from a project located in the lower reaches of the Navasota River and,

2. Determine the desirability of meeting the above requirements from such a project.

This study was made in accordance with the provisions of the Memorandum of Agreement dated November 4, 1958, between the Department of the Army and the Department of Health, Education, and Welfare, to provide assistance in implementing the Water Supply Act of 1958.

Scope

The project in question will be referred to herein as Millican Reservoir. The structure, an earth fill dam with a gate controlled spillway in a saddle on the left bank, will be located at river mile 24.05 on the Navasota (a tributary of the Brazos River). This structure will provide 672,500 acre-feet of conservation storage which will have a firm yield of 350 cfs (226 mgd).

The prospective needs of the cities of Bryan, College Station, and Navasota, for municipal and industrial water supply, were studied. The municipal and industrial water supply needs of water users in the entire lower Brazos River Basin were also studied.

This report, for the Navasota River, is one of a series of three companion reports on projects being studied for the tributaries of the lower Brazos River. The other two reports are concerned with projects located on the San Gabriel River and Yegua Creek. These projects are related from a water supply standpoint, in that a common market for municipal and industrial water will exist in the lower Brazos River Basin.

Acknowledgments

The cooperation and assistance of those listed below in providing information necessary to the preparation of this report are appreciatively acknowledged.

Geological Survey, U. S. Department of the Interior,
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Texas State Department of Health, Austin, Texas

Brazos River Authority, Waco, Texas

F. C. Sandlin, City Manager, Bryan, Texas

Bryan - College Station Chamber of Commerce, Bryan, Texas

William F. Guyton and Associates, Consulting Ground-Water Hydrologists, Austin, Texas

E. Jack Turner, General Water Superintendent, Dow Chemical Company, Freeport, Texas

SUMMARY AND CONCLUSIONS

Summary

1. This report is concerned with questions of water supply storage in Millican Reservoir on the Navasota River, a tributary of the Brazos. Water requirements are given in two parts: (1) those for the local area in the Navasota watershed, and (2) those for the lower Brazos River Basin, from Waco to the Gulf of Mexico.

2. The projected water requirements for the local area (consisting of the cities of Bryan, College Station, and Navasota) are 35.9 mgd by the year 2010. Of this amount, Bryan and College Station will probably continue to be supplied by at least 15.0 mgd from the ground water of the Sparta Sands. Navasota will probably continue to meet its needs from the ground water of the Catahoula formation.

3. For the lower Brazos area as a whole, it is projected that 1,102 mgd will be needed by 2010.

4. The aggregate firm yield from surface reservoirs, existing and proposed, totals slightly over 510 mgd. The maximum capability of ground water in the area is unknown, but is believed to be in the order of 50 mgd.

5. The deficiency of supply to future demand indicated above, is partially offset by the fact that the figures represent gross takeout from sources, a portion of which will be returned to the stream for subsequent reuse. Nevertheless, additional measures will be required to increase the dependable supply, if growth is to occur as projected. In this connection it may be noted that a regulated surface supply of 510 mgd is a small part of the average annual runoff of about 4,600 mgd.

Conclusions

1. Storage for water supply, in the maximum amounts which can be economically provided, should be included in all projects planned for the lower Brazos River system.

2. The quality of Navasota River water is satisfactory for municipal and industrial water supply purposes. The maintenance of stream quality objectives in the Navasota and Brazos Rivers is a problem which calls

for careful attention by the agencies responsible. Additional information concerning this problem is needed and should be provided by the studies now in progress for the U. S. Study Commission - Texas.

3. Based on the economic analysis of a regional alternative plan of water supply, the average present values of benefits for the water supply storage of the five reservoirs considered in this study are shown below. Further details are given in the last chapter of this report.

Reservoir	Average Annual Present Value	Yield (mgd)	Present Benefits (¢/1000 gal. of yield)
Stillhouse Hollow	$ 515,000	63	2.24
Somerville	414,000	34	3.34
North San Gabriel	284,000	19	4.10
Millican	826,000	226	1.00
South San Gabriel	120,000	11	2.99
Sum or Average	$2,159,000	353	1.68

LOCATION OF THE STUDY AREA

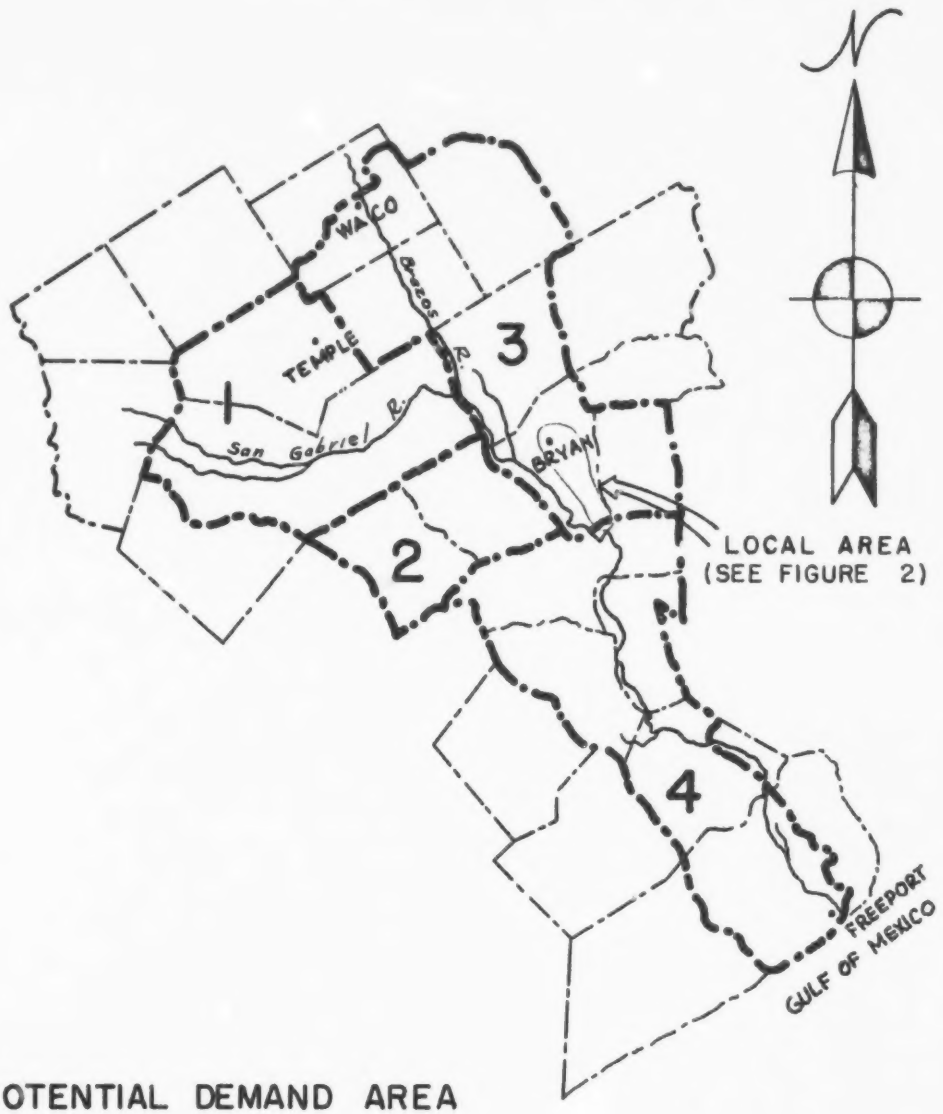
Lower Brazos River Area

The boundary that defines the total area encompassed by this study is shown on Figure 1. This boundary was chosen so as to include the entire area which might be served, through one integrated plan, from reservoirs on the San Gabriel River, Millican Reservoir on the Navasota River, Somerville Reservoir on Yegua Creek, Stillhouse Hollow Reservoir on the Lampasas River, the existing Belton Reservoir on the Leon River, and the enlarged Lake Waco on the Bosque River. The major water demand centers of this area probably will develop in the vicinities of Waco and Freeport; therefore, the decision was made to make the length of the study area run roughly from Waco in the north to Freeport on the southern coast. The east-west boundaries generally follow the boundary of the Brazos River Basin but are modified to some extent with consideration being given to the political boundaries which nearly coincide with this basin boundary. It was necessary to make the total study area boundary follow county or precinct lines in order to facilitate the use of U. S. Bureau of Census population data.

The total study area includes Limestone, Falls, Bell, Williamson, Milam, Robertson, Brazos, Grimes, Burleson, Washington, Waller, and Austin Counties. Also included are portions of McClennan, Lee, Fort Bend, and Brazoria Counties.

Local Area

The local area, as shown on Figure 2, comprises the cities of Bryan and College Station in Brazos County and the city of Navasota in Grimes County. These cities were given detailed study for two reasons: (1) their apparent need for additional water supply sources beyond what they have developed at present, and (2) the possibility that water from the Corps project under study could be supplied directly to these cities via a pipeline. The relative locations of the local area and the total study area are shown on Figure 1.



POTENTIAL DEMAND AREA
LOWER BRAZOS RIVER
NO SCALE

VICINITY MAP

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REGION VII DALLAS, TEXAS

FIGURE 1

5-b

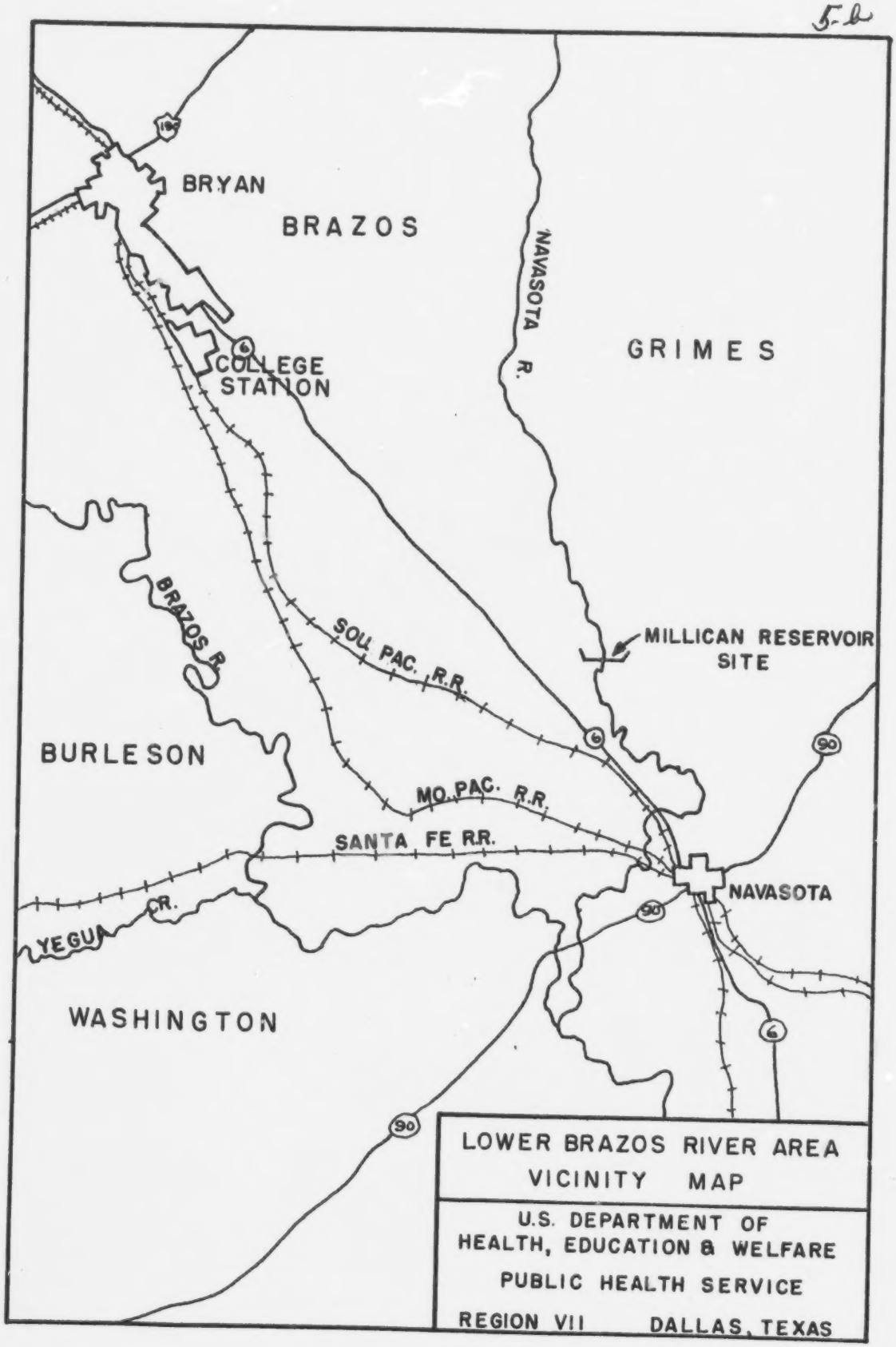

BRYAN
BRAZOS
NAVASOTA R.
GRIMES
COLLEGE STATION
BRAZOS R.
SOU. PAC. R.R.
MILLICAN RESERVOIR SITE
BURLESON
MO. PAC. R.R.
SANTA FE R.R.
NAVASOTA
YEGUA CR.
WASHINGTON
LOWER BRAZOS RIVER AREA
VICINITY MAP
U.S. DEPARTMENT OF
HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 2

LOWER BRAZOS RIVER AREA

Geography

The Brazos River flows in a general southeasterly direction through this area to the Gulf of Mexico. The slope of the river bed varies from approximately 1.2 feet per mile near Waco to less than 0.5 feet per mile near the Gulf. The average flow over 35 years of record at Richmond has been 7,173 cfs, as measured by the U. S. Geological Survey. At Juliff, a city below Richmond, the river has been dry at times due to heavy pumping withdrawals.1/ The records of both gaging stations reflect the effect of regulation by upstream reservoirs.

In the lower Brazos River Basin, the terrain changes from rolling hills in the northern portion to a flat coastal plan surrounding Freeport in the southern section. The table-like topography of the alluvial plain along the main channel of the Brazos River does not afford economical reservoir construction sites.2/ The flood plain has extensive agricultural development, many highways, railroads, and communities which deter the possible use of this area for reservoirs. For the above reasons, the reservoirs (existing and planned), previously mentioned as being possible surface water sources for the area, are located a number of miles upstream from the major potential water customer--that is, the industrial complex centered in the city of Freeport.

The lower Brazos area is characterized by a mild and fairly uniform climate. The mean annual temperature varies from about 70 degrees in the coastal area to 66 degrees in the vicinity of Waco.3/ From Waco to the Gulf Coast, the normal annual rainfall varies from 33 inches to 47 inches.3/ The average length of the growing season ranges from 260 days in the northern portion to 320 days near the coast.3/

Economic Analysis

General

The economic growth of the lower Brazos River area will depend on the presence of natural resources and their level of utilization, the extent and present pattern of industrial development, and the future development of the market for goods and services. The population increase in this area will chiefly depend on the future economic growth of the area. A demographic and economic analysis explains the past growth trends of the area and should give a good indication of its growth potential.

Resource Extraction

Oil and natural gas production is of major importance in the Gulf Coast portion of the lower Brazos area. Austin, Brazoria, and Fort Bend Counties are among the nation's largest producers of oil and gas.[4] Also, in the southern area, there are sulphur mining activities, and magnesium is being extracted from seawater. In the northern segment of the area surrounding Waco, there are sand and stone quarrying, and coal mining.

Agriculture

Agriculture is one of the most important activities and is practiced, to some extent, over the entire area. However, it is most important in supporting the economies of Brazos, Burleson, Grimes, Lee, Milam, Robertson, and Williamson Counties. The aggregate acreage of cropland harvested in these particular counties was 781,808 in 1944, 793,605 in 1949, and then fell off to 746,371 acres in 1954.[5,6] For these same years the value of all farm crops sold showed a steady increase from $13,319,000 to $22,906,000.[5,6] In 1944 the value of livestock and livestock products sold was $12,155,000; this figure rose to $13,993,000 in 1954.[5,6] The agricultural value figures shown here have been adjusted to compensate for the change in the value of the dollar since 1944.

Manufacturing

In the northeast section of this area presently under discussion, manufacturing plays the paramount role in the economy. In 1954, the counties of Bell, Brazos, Limestone, and McClennan had 61 per cent of the total number of manufacturing firms located in the 15-county lower Brazos River area.[7,8] The four-county segment of the total area had 210 firms in 1947 and 250 firms in 1954.[7,8] In this segment of the study area near Waco, firms are concerned with the manufacture of stone, clay, glass, and rubber products. The manufacture of furniture, apparel, and paper products also supports this area. In addition, an alumina reduction plant is located here. In the southern section of the lower Brazos area, the manufacture of petrochemicals on a very large scale is probably the most important single item in the manufacturing activity of that area.

Population

The projected population given herein for the entire lower Brazos River area includes all people who live in organized communities (which would have public water supply systems) and excludes those living outside such cities. This population has shown a trend of steady growth in the period from 1930 to 1960. In 1930 the total population was 164,300 and by 1960 this figure had risen to 340,000.[9] Also, the municipal population being discussed here makes up a larger

segment of the total gross population of the area. The significance of this trend toward urbanization is illustrated by the change in the relative numbers living in cities and towns; in 1930, 34 per cent lived in the municipalities, and by 1960, it was an estimated 57 per cent.[9/]

Prospects for Growth

General

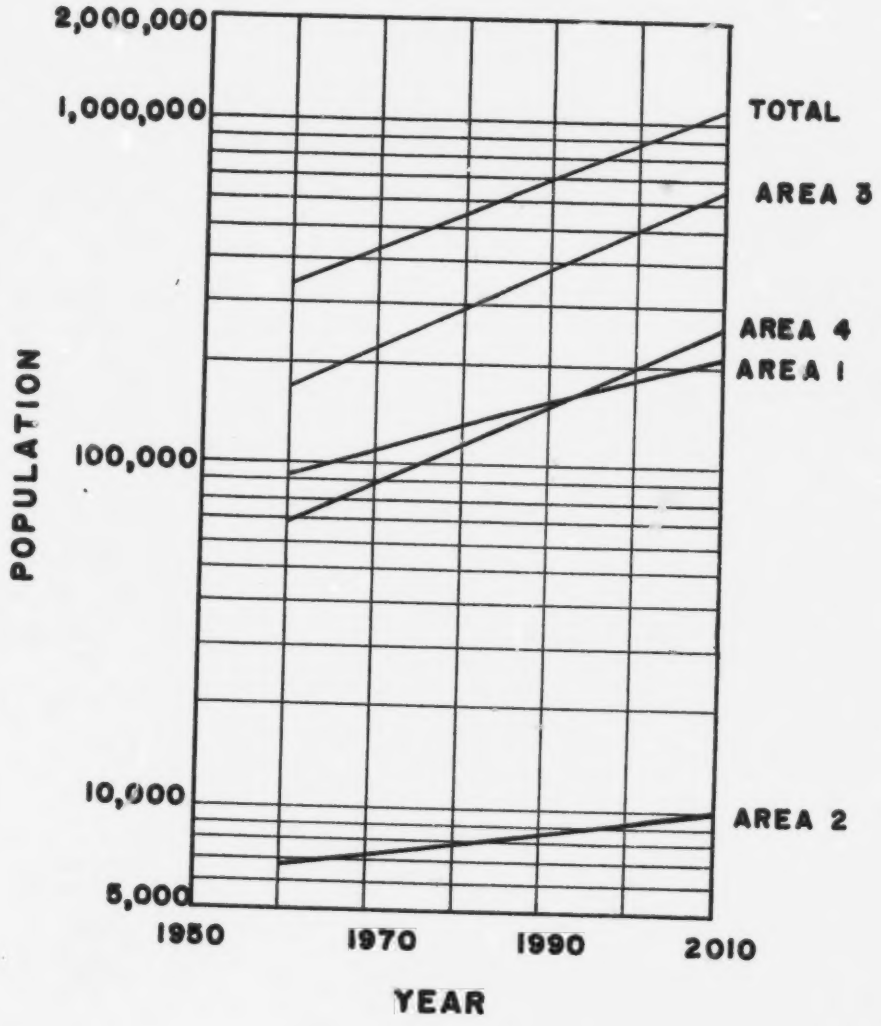
The population of the nation is expected to double between 1960 and 2010. As this population increase takes place, a vast increase in the demand for goods and services will appear. The more favorably endowed an area is with the elements which enable it to produce and distribute goods and services--the greater chance it has for future expansion and growth.

Growth Factors

The future expansion of the economy of the area will depend upon the growth potential of its various segments. In agriculture, the production of crops, livestock, and livestock products is expected to increase only slightly, but the number of agricultural employees will decline due to further mechanization. Increases in food and feed processing can, however, be anticipated. It is expected that the manufacturing industries producing stone, clay, and glass products near Waco will enjoy substantial growth because of the availability of supplies of raw materials necessary for the operation of these industries. The manufacturing activities in the Waco area may also show accelerated growth from the already present base because of expectations that the markets for these products will expand. Farther south, in the area between Rosenburg and Freeport, it is forecast that the petrochemical industries will show a ten-fold production increase in the next 50 years because of the plants already located there and the plentiful supply of oil and gas in the area. The magnesium extraction might also expand, since all the necessary materials for production are present locally.

Population Forecasts

Population forecasts were made for each of four subdivisions (as shown on Figure 1) of the study area. The four trends and a forecast for the total area are shown on Figure 3. In making these forecasts consideration has been given to published documents[4/], historical growth patterns, and information obtained in field investigations. They are, of course, influenced also by the future economic growth just described.



LOWER BRAZOS RIVER AREA

POPULATION TRENDS

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PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 3

Present Sources of Water Supply

The surface and ground water resources of the lower Brazos Basin can, at present, furnish approximately 210 mgd of dependable supply to the users in this area. Lake Waco and Lake Belton are presently the chief surface water sources in this area and together are able to furnish an estimated 160 mgd. According to the records of the Texas State Health Department, the mineral and organic quality of the water is good in the Bosque and Little Rivers. Lake Waco is in the Bosque River watershed and Lake Belton is located in the Little River watershed. However, once the water of these two tributaries of the Brazos River enters the main channel of the Brazos, the mineral quality of this water deteriorates - as will be discussed later in this report. It is estimated that the underground sources of water are capable of supplying approximately 50 mgd, thus bringing the total yield of present supplies in the area to 210 mgd.

Water Requirements

The municipal and industrial water requirements for this area are shown in Table 1. The requirements are indicative of gross intake by the water users and do not reflect the fact that a substantial amount of the water used by upstream consumers will be returned to the stream - eventually to be reused by downstream users. The gross requirements were separated into industrial and nonindustrial water uses. Industrial water, as the term is used herein, is water used by basic industries (those which produce goods for sale outside the area, and thus bring income into it). Nonindustrial water is that water used for functions other than those performed by basic industries.

The projected industrial water requirements were obtained after careful consideration of the growth potential in 16 of the basic industrial categories which use over 90 per cent of the industrial water in the area. The present level of development in each category was compared to development on a national level, so as to obtain an indication of the relative share of the national market that each category holds. Those industrial categories which have less than their share of the national market were projected at a higher rate of growth than expected nationally. Those categories which have more than their share of the national market are expected to maintain their relative percentage of the market in the future. Once a trend in production was assumed for a particular industrial group, a trend in water use was projected. In industries that are large water users, this trend, expressed as water requirements per unit of production, was lowered in anticipation of more efficient water use (i.e., cooling towers and other methods of cooling). Data collected in the field were utilized in making these projections. In addition, trends in production and water use as shown in Water Resources Activities in the United States[10] were studied.

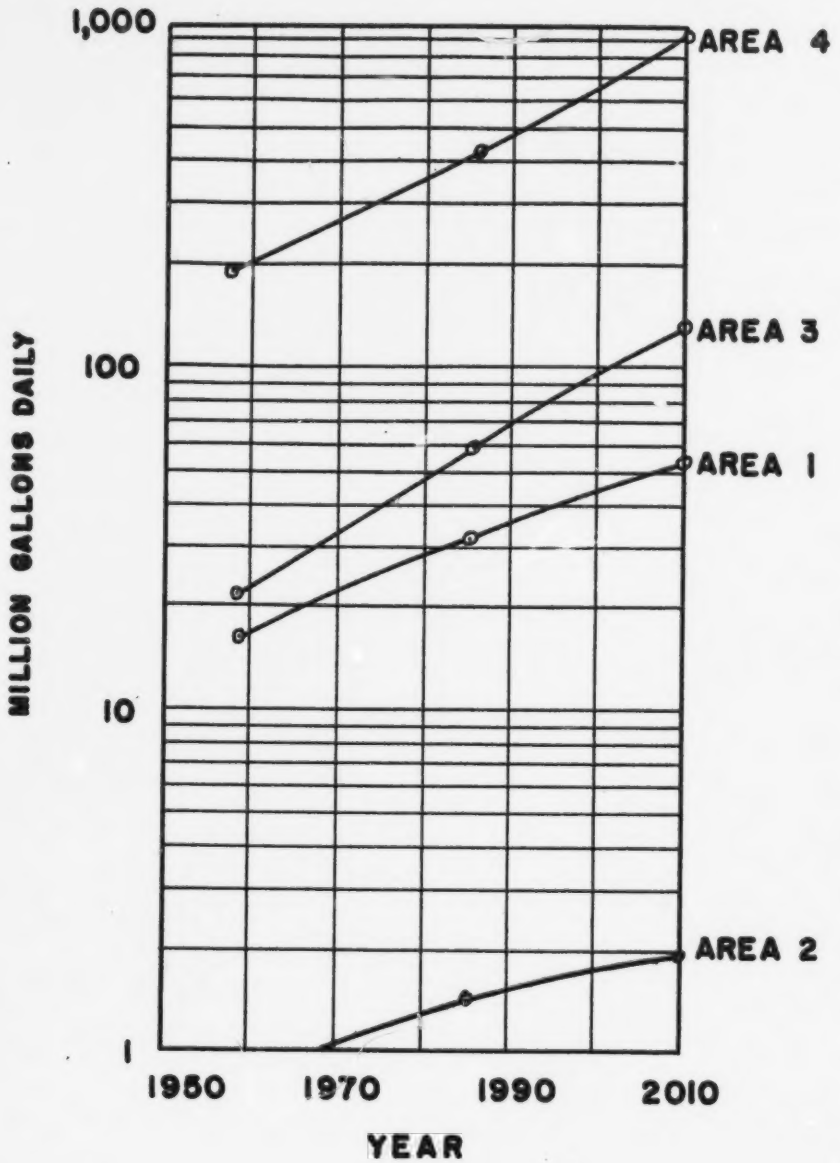
The nonindustrial water requirements for this area were prepared through the use of the previously mentioned projected populations and nonindustrial per capita water consumption figures. An average per capita use of 120 gpcd was used for the entire area in 1958. This is an average based on data reported to the Texas Health Department by typical cities in the area. In 1985 and 2010, the per capita consumption figures are an average of figures obtained from preliminary U. S. Study Commission work papers and a publication entitled Water for the Future[4/] by the Bureau of Business Research, University of Texas.

By reference to Table 1, one can see the basic information necessary to the formation of Figures 4 and 5.

Table 1

Lower Brazos River Area Water Requirements

Sub-Area	Forecast Population	Nonindustrial Use (gpcd)	Average Annual Water Requirement (mgd) Nonindustrial	Industrial
		Year 1958		
1	90,000	120	10.8	5.5
2	6,700	120	0.8	0.01
3	163,000	120	19.6	1.9
4	66,500	120	8.0	181.0
	326,200	Estimated Total Requirements, 1958 - 227.6 mgd		
		Year 1985		
1	143,000	162	23.2	9.7
2	8,300	153	1.3	0.06
3	330,000	162	53.5	4.3
4	136,000	149	20.3	406.0
	617,300	Estimated Total Requirements, 1985 - 518.4 mgd		
		Year 2010		
1	213,000	190	40.5	13.0
2	10,200	170	1.7	0.2
3	660,000	190	125.4	7.3
4	260,000	165	42.9	870.7
	1,143,200	Estimated Total Requirements, 2010 - 1,101.7 mgd		



LOWER BRAZOS RIVER AREA
WATER REQUIREMENTS

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FIGURE 4

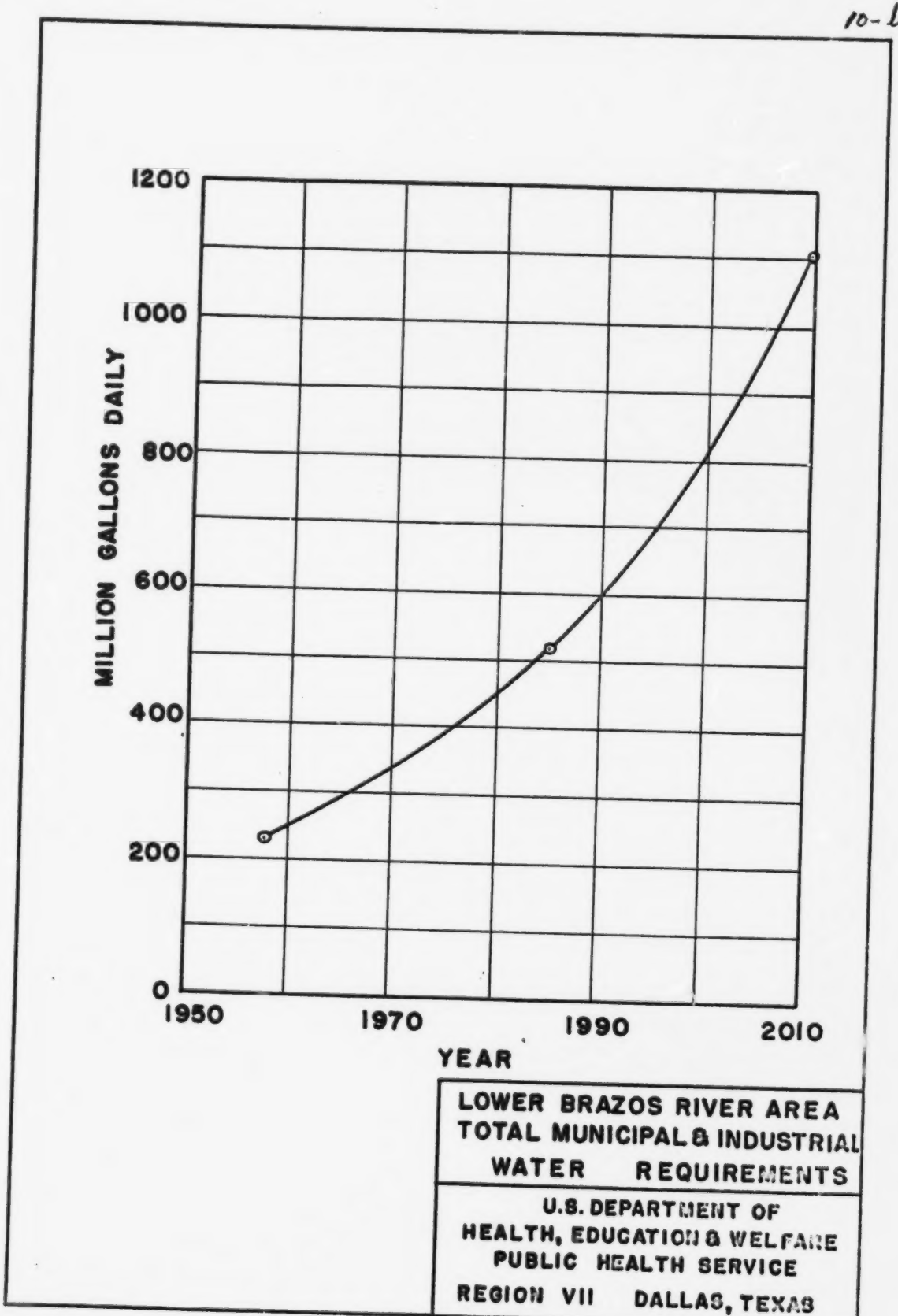

1200
1000
800
600
400
200
0
MILLION GALLONS DAILY
1950
1970
1990
2010
YEAR
LOWER BRAZOS RIVER AREA
TOTAL MUNICIPAL & INDUSTRIAL
WATER REQUIREMENTS
U.S. DEPARTMENT OF
HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 5

Waste Disposal

Due to high concentrations of dissolved solids, principally caused by salt springs and gypsum outcroppings located in the upper reaches of the Brazos River, the water in the main channel is largely unsatisfactory for municipal and industrial use upstream from Whitney Dam.2/ This point will be more fully discussed later in this report.

In the reach of the Brazos River between Waco and a point near river mile 20 (which marks the approximate limit of upstream intrusion into the main channel by sea water) the disposal of treated organic wastes produced by the population in the area, and to some extent by chemical industries, could degrade the water quality--unless stream flows are maintained at a level where they are able to assimilate the wastes. It is assumed that these organic wastes will be treated for the removal of 90 per cent of the B.O.D. (biochemical oxygen demand). Studies are now underway which will furnish estimates of the amounts of water needed to maintain quality objectives after the wastes are treated. These studies are being made as a part of a comprehensive consideration of water quality in Texas intrastate streams for the U. S. Study Commission - Texas. Water quality data being collected by the Texas State Health Department will be greatly utilized in these studies.

In the reach of the Brazos described in the preceding paragraph, manufacturing is the most prevalent type of industry. The existing manufacturing processes do not produce large amounts of organic waste. The mineral wastes resulting from future manufacturing, which is expected to be in the primary metals, will (presumably) be treated to such an extent that no adverse stream conditions will be created.

The petrochemical industry is expected to expand ten-fold within the next 50 years along the Gulf Coast of Texas. The segment of the Brazos River which will be affected by the large amounts of wastes from this industry will be principally the area where sea water intrudes the fresh water of the Brazos River. The usefulness of this water probably will not be impaired due to quality characteristics, provided the organic wastes from the petrochemical industry are given adequate treatment before being discharged to the river. This is because a major portion of the water used in this area is for cooling purposes for which it is possible to use a water with a relatively high mineral content.

The foregoing statements are subject to qualification in the event that a salt-water barrier is built, to bring the high quality fresh water channel closer to the coast. In that case, it would be necessary to divert the industrial wastes to a separate channel.

LOCAL AREA

Geography

The Navasota River flows in a southerly direction past Bryan, College Station, and Navasota to its confluence with the Brazos River. On April 26, 1957, at the U. S. Geological Survey stream gaging station near Bryan, which was made operative on January 1, 1951, a maximum discharge of 35,800 cfs was recorded for the Navasota River. In contrast, during the seven-year period of record, there have been periods of no flow, averaging about 40 days' duration annually. The average flow of the Navasota River, as recorded at this particular gaging station, has been 410 cfs.

The terrain ranges from rolling to hilly in the local area. The soil is a rich, alluvial type along the stream channels and varies from this to a heavier type soil in the uplands.3/

The annual growing season of this local area averages about 259 days. The mean annual temperature is 68 degrees and the normal annual rainfall of this area is approximately 39.5 inches.3/

Economic Analysis

General

The economic growth of the local area surrounding the project under study will depend on the presence of natural resources and their level of utilization, the extent and present pattern of industrial development, and the future development of the market for goods produced in the area. The population increase of the cities of Bryan, College Station, and Navasota will depend in large part on the economic growth of the surrounding area. A demographic and economic analysis of the two counties within which these cities lie, will help explain the past growth trends of these cities, and will also give a good indication of their future growth potential. Bryan and College Station, which are in Brazos County, will be considered a population node.

Resource Extraction

The extraction of mineral resources in Brazos and Grimes Counties has been of minor importance in the economy of these two counties. Mineral extraction has been confined to petroleum and natural gas.11/ The total value of minerals extracted in Brazos and Grimes Counties from 1952 to 1958 has been averaging only $211,000 annually.11/ See Table 2.

Table 2

Value of Mineral Production - Brazos and Grimes Counties
1952 - 1958

County	1952	1953	1954	1955	1956	1957	1958
Brazos	$ 31,901	$ 58,250	$ 20,842	$ 20,720	$ 22,300	$ 29,700	$ 20,000
Grimes	72,198	180,897	116,520	99,152	99,550	224,220	483,450
Total	$104,099	$239,147	$137,362	$119,872	$121,850	$253,920	$503,450

There are no forest reserves in Brazos County, but Grimes County has approximately one-third of its land area available for commercial forestation.3/ In 1955 Grimes County produced approximately 1 per cent of the State's pulpwood and 1 per cent of the State's total sawtimber volume.12/ However, since 1955 the trend in Grimes County has been away from the utilization of the timber resources located there.

Agriculture

The agricultural phase of the economics of Brazos County is becoming decreasingly important. The number of farms and the acreage of cropland harvested have declined steadily since 1944.5,6/ The value of crops sold rose from $1,209,632 in 1944 to a figure of $1,980,000 in 1954, adjusted to the common dollar value of 1944 to reflect the relative volumes on a comparable base.5,6/ The comparable values of livestock products show a decrease from $1,446,530 in 1944 to an adjusted value of $1,010,000 in 1954.5,6/

On the other hand, agriculture is a very important factor in maintaining the economy of Grimes County. The value of crops and livestock products sold has shown a steady increase from $2,157,890 in 1944 to an adjusted value of $4,320,000 in 1954.5,6/ However, both the number of farms and the acreage of cropland harvested have been declining in recent years.5,6/

Manufacturing

Manufacturing has shown very substantial expansion and is a very important factor in the economy of Brazos County. The city of Bryan is the focus for manufacturing in this county with approximately 70 per cent of the county's total manufacturing employees located there.7,8/ In the county, expansion has taken place since 1947 in the number of firms connected with food and kindred products, printing and publishing, fabricated metal products, furniture and fixtures, chemicals and chemical products, rubber products, and miscellaneous manufacturing.7,8/ In 1947 three of these firms had over 20 employees and in 1958 there were eight firms in the county with over 20 em-

ployees.[7,8] The number of manufacturing employees in the county grew from 308 in 1947 to 843 in 1958 and in the same period the value added by manufacturing rose from $1,368,000 to $5,010,000 adjusted to compensate for the change in the value of the dollar since 1947.[7,8]

Manufacturing activities in Grimes County showed a downward trend from 1947 to 1954, but since 1954 have begun to show a partial recovery from the previous decline.[7,8] The number of manufacturing employees was 289 in 1947, dropped to 115 in 1954, and then climbed back to 146 in 1958.[7,8] The value added by manufacturing followed a pattern of fluctuation similar to that of the number of manufacturing employees; it was $978,000 in 1947, $476,000 in 1954, and $815,000 in 1958.[7,8] The 1954 and 1958 values have been adjusted to reflect the change in the value of the dollar since 1947. The number of firms with 20 or more employees was 6 in 1947, fell off to 2 in 1954, and rose to an estimated 4 in 1959.[7,8] The drop in the number of firms with 20 or more employees was greatest in the lumber and wood products industries; however, expansion has been shown in plants associated with food and kindred products, furniture and fixtures, and fabricated metal products.[7,8]

Population

The total population of Brazos County has shown an upward trend in the period from 1910 until the present. In 1910 the total population was 18,919 and by 1960 it had increased to 44,605 or about 2-1/2 times the 1910 population.[9] The municipal population, consisting of residents of Bryan and College Station, has also shown an upward trend since 1910. The municipal population is 38,678 in 1960 or about 9-1/2 times the comparable figure for 1910.[9] The population living outside the cities of Bryan and College Station showed a downward trend between 1910 and 1960. The significance of the trend toward urbanization is indicated by the change in the relative numbers living in cities and towns; in 1910, 22 per cent lived in the municipalities, whereas in 1960 it was an estimated 87 per cent.[9]

The total population of Grimes County has exhibited a steady downward trend from 23,101 people in 1920 to an estimated 11,000 in 1960.[9] The municipal population of this county, made up of residents of Navasota, increased from 5,060 in 1920 to 6,138 in 1940 but fell to 4,875 in 1960.[9] The population in Grimes County living outside the city of Navasota has declined steadily from 18,041 in 1920 to 7,263 in 1960.[9] Again, it is important to note the trend toward urbanization in this county. In 1920, 22 per cent lived in Navasota and by 1960 a comparable figure was 39 per cent.[9]

Prospects for Growth

General

The population of the nation is expected to double between 1960 and 2010. As this population increase takes place, a vast increase in the demand for goods and services will appear. The more favorably endowed an area is with the elements which enable it to produce and distribute goods and services - the greater chance it has for future expansion and growth.

Growth Factors

Brazos County and the cities of Bryan and College Station, which are located therein, possess a great many of the elements necessary for future growth and expansion. Two railroad companies, the Missouri Pacific and the Southern Pacific, plus two major highways, crossing this population node provide good transportation facilities. In addition, regular scheduled airlines are available. The relative costs of fuel and power are low with large supplies of fossil fuels located within economical transmission distances to the cities. The market area surrounding Bryan and College Station consists of Brazos, Grimes, Robertson, Madison and Burleson Counties. Most of the market-oriented manufacturing firms located in this five-county area are concentrated in the cities of Bryan and College Station. As the area grows, these two cities should expand their manufacturing enterprises from the excellent base presently centered there. Expansion should take place in firms connected with food and kindred products, printing and publishing, fabricated metal products, furniture and fixtures, chemicals and chemical products, rubber products, and miscellaneous other types of manufacturing. An additional factor that will help maintain a favorable environment for expansion is the presence of Texas A & M College in College Station.

The city of Navasota, located in Grimes County, has good transportation facilities available with two main highways, the Missouri Pacific Railroad and the Santa Fe Railroad passing through it. The availability and relative cost of fuel and power are essentially identical to those same items in the Bryan-College Station node. Agriculture should remain an important element in the economy of Navasota. This area is well adapted to farming with the soil type varying from heavy to sandy.3/

Population Forecasts

On the basis of the foregoing analysis of the prospects for future growth, the forecasts of population trends are as shown in Table 3.

Table 3

Forecasted Populations for Local Area

Community	1960	1985	2010
Bryan and College Station	38,678	96,000	168,000
Navasota	4,875	6,600	8,700

Present Sources of Water Supply

In the Bryan-College Station locale, the Sparta Sand formation is the ground water aquifer from which these two cities derive their present water supplies. At this writing, these municipalities have 16 wells which develop an estimated 14.8 mgd[13] of excellent[14] quality water. The optimum yield capability of the Sparta Sand formation is not known at this time. A detailed geological study and a design of an expanded well field must be made before the capacity of this formation can be estimated.[14]

The Catahoula Sandstone aquifer, from which the city of Navasota develops well-water supply, furnishes water of acceptable quality.[15] The total dissolved solids occur in concentrations approximating 600 ppm.[15] The ultimate capacity of this sand formation is unknown; however, it is estimated that the present system of five wells can furnish the city of Navasota 1.9 mgd.[13] When these wells must be replaced, it should be possible to construct new wells in the Catahoula Sandstone aquifer as replacements.

Water Requirements

The water requirements for the cities in the local area are presented in Table 4 with corresponding population and per capita use figures. The populations shown in Table 4 have been discussed earlier in this report. The per capita usage figures are estimates based on water use data obtained from the Texas State Health Department; the Bureau of Business Research, University of Texas; and preliminary data compiled for the U. S. Study Commission - Texas.

Table 4

Local Area Water Requirements

Municipality	Year	Forecast Population	Nonindustrial Use (gpcd)	Average Annual Water Requirement (mgd)	
				Nonindustrial	Industrial
Bryan and College Station	1960	38,678	120	4.65	0.50
	1985	96,000	162	15.55	1.50
	2010	168,000	190	31.90	2.50
Navasota	1960	4,875	100	0.49	0.03
	1985	6,600	120	0.79	0.04
	2010	8,700	165	1.44	0.09

Waste Disposal

Currently the cities in this local area (Bryan, College Station, and Navasota) are providing secondary treatment of their municipal and industrial wastes.16/ Effluent from Bryan's newest waste treatment facility is discharged into Thompsons Creek which ultimately routes the effluent into the Brazos River. The effluent from College Station's plant is released to Carters Creek, east of the city, and flows along this water course until it ends up in the Navasota River. The wastes from the city of Navasota are discharged to the Navasota River after treatment.

When Millican Reservoir becomes a reality, the treated municipal and industrial wastes from the Bryan-College Station node, if discharged to the Navasota River, could produce conditions in the reservoir which would be esthetically undesirable, a danger to public health and aquatic life, and an impairment to recreational uses. It appears that the problem could best be solved by diverting all (or most of) the wastes from this node to the Brazos River. It is estimated that by the year 2010 these wastes will have to be mixed with stream flows of 24 mgd on the average and 43 mgd during critically hot and dry months (from about June through September), in order to maintain stream quality objectives. These estimates of flows were made assuming 90 per cent removal of B.O.D. during the waste treatment process.

Again assuming 90 per cent B.O.D. removal and critical temperature and flow conditions, it is estimated that by 2010 the waste discharges from the city of Navasota will require approximately 2 mgd of stream flow to maintain 4.0 ppm of dissolved oxygen. It is anticipated that the minimum releases from Millican Reservoir, which would be located upstream from the discharge point of Navasota's wastes, will greatly exceed 2 mgd. Therefore these specific wastes should not cause any problems related to esthetics or health.

THE NAVASOTA AS A FUTURE SOURCE OF WATER SUPPLY

Quantity Available

According to preliminary data furnished by the Corps of Engineers, the storage for municipal and industrial water supply to be included in Millican Reservoir should provide a firm yield of 350 cfs (226 mgd). It is estimated that the gross needs of the Bryan-College Station population node will be 34.4 mgd by the year 2010. The present facilities of these two cities combined can furnish about 15 mgd. The city of Navasota will have a requirement of 1.53 mgd by 2010 and has present facilities which are able to furnish 1.9 mgd.

Most of the firm yield from Millican Reservoir will probably be used by subarea 4 (see Figure 1). The total municipal and industrial water requirements of this subarea will be 914 mgd by 2010.

A portion of the present supply to subarea 4 is derived from ground water. However, since the availability of ground water in the area is limited, this source of water will supply only a small portion of subarea 4's total demands by 2010. And, because Millican Reservoir will not be able to completely supplement ground water to meet the total demands, it is necessary to comprehensively study the supplies and requirements of the entire lower Brazos River area.

The total municipal and industrial water requirements of the entire lower Brazos River area are expected to be 1,102 mgd by the year 2010. The existing and proposed supply sources for this area are presented in Table 5. The estimated yields shown for the surface water impoundments are from only the water supply (conservation) storage volume included in each reservoir. A portion of the yields from this conservation storage space is presently allocated to meet irrigation needs. It is infeasible at this time to estimate whether an increase or a decrease will take place in the volume of water allocated to irrigation uses.

Table 5

Existing and Proposed Water Sources - Lower Brazos River Area

Source	Estimated Yield (mgd)
Lake Waco (existing enlarged)	55
Lake Belton (existing enlarged)	105
Stillhouse Hollow Reservoir (proposed)	63
San Gabriel River Project(s) (proposed)	30
Millican Reservoir (proposed)	226
Somerville Reservoir (proposed)	34
Ground Water (present and future development)	50
Total	563 mgd

It can be concluded from comparing the expected total water requirements of 1,102 mgd by 2010 with the total estimated yield of 563 mgd, that a demand exists for the maximum feasible amount of municipal and industrial water supply storage that can be economically developed in the proposed Millican Reservoir.

The deficiency of supply to future demand indicated above is partially offset by the fact that the figures represent gross takeout from sources, a portion of which will be returned to the stream for subsequent reuse. Nevertheless, additional measures will be required to increase the dependable supply, if growth is to occur as projected. In this connection it may be noted that a regulated surface supply of 510 mgd is a small part of the average annual runoff of about 4,600 mgd.

Quality of Water

The Texas State Department of Health, as part of a statewide water quality survey, has been taking biweekly stream samples at the intersection of U. S. Highway 190 and the Navasota River for the past 2-3/4 years. A summary of analyses of the available data from this particular sampling station is presented in Table 6.

Table 6

Chemical Quality - Navasota River at Bridge on U. S. Highway 190
(Period of Record - 10/17/57 through 4/11/60)

	Total Solids (ppm)	Chlorides (ppm)	Sulphates (ppm)
Maximum	1,200	460	100
Minimum	43	12	8
Arithmetic Average	407	131	41

The chemical quality of the Navasota River is presently good (for municipal and industrial purposes) and should remain so in the future. The concentration of chlorides has exceeded the recommended limit of 250 ppm[17] in 12 per cent of the samples. This is due, in part, to oil field brines entering the river above the sampling point. The concentration of total dissolved solids exceeded the recommended desirable limit of 500 ppm[17] in 19 per cent of the samples and exceeded the recommended maximum limit of 1000 ppm[17] in 2 per cent of the samples.

Under present conditions of municipal and industrial organic waste loading, the Navasota River has no problems with respect to organic pollutants. The B.O.D. concentration has averaged 1.2 ppm and the dissolved oxygen concentration has averaged 6.7 ppm. As mentioned

previously in the discussion of waste disposal in the local area, organic pollutants could create water quality problems if they are allowed to enter the Navasota River in uncontrolled concentrations.

The high mineral concentrations prevalent in the water of the main channel of the Brazos River above Lake Whitney place severe limitations on using it for municipal and industrial purposes. These high concentrations are caused by salt springs and gypsum outcroppings located upstream from Lake Whitney. Table 7 shows data collected by the U. S. Geological Survey.

Table 7[18]/

Chemical Quality - Brazos River Near Whitney, Texas

Water Year	Mean Daily Discharge (cfs)	Weighted Average Concentrations (ppm)	
		Chlorides	Sulphates
1948-49	1,566	242	172
1949-50	1,520	244	157
1950-51	840	437	260
1951-52	348	332	167
1952-53	141	209	112
1953-54	912	392	198
1954-55	997	374	205
1955-56	1,571	333	255
1956-57	6,213	126	96

As the water in the main stem moves downstream, higher quality water (lower concentrations of minerals) enters from tributaries and dilution takes place. The effects of this dilution water on the concentrations of chlorides and sulphates may be seen by comparing Table 7 and Table 8. The data shown in Table 8 are also from U. S. Geological Survey records.

As shown by the comparison of Tables 7 and 8, the chemical quality of the water in the main channel of the Brazos River improves as the water flows downstream and is diluted with water from tributary streams. Nevertheless, the concentrations of chlorides and sulphates as far downstream as Richmond are, at times, still high enough to produce water of mediocre to poor quality. Unless and until the upstream sources of mineral contamination are effectively eliminated, the quality of the Brazos water will remain at such a level as to make questionable a decision to use this water for municipal and industrial purposes. Studies made jointly by the Brazos River Authority, the Texas State Department of Health, and the U. S. Geological Survey have located the sources of contamination. It is felt that the water

quality impairment by these sources will be reduced and that the chemical quality of the Brazos River water will improve in the future. This should make possible the utilization of a substantial portion of the runoff in the main stem, which averages about 1,100 mgd above Waco, Texas.

Table 8[18]/

Chemical Quality - Brazos River at Richmond, Texas

Water Year	Mean Daily Discharge (cfs)	Weighted Average Concentrations (ppm)	
		Chlorides	Sulphates
1948-49	4,645	103	76
1949-50	5,783	87	58
1950-51	1,418	214	134
1951-52	1,820	85	54
1952-53	4,105	31	25
1953-54	2,727	127	72
1954-55	2,168	145	83
1955-56	2,185	260	185
1956-57	15,290	65	54

VALUE OF STORAGE

General

The preceding sections of this report have shown the projected water needs of the lower Brazos River area, and the physical feasibility of meeting a part of the need by storage in the multiple-purpose projects under study. The question of economic feasibility leads to consideration of the monetary value, or benefits, of water supply storage.

Efforts to approach this problem on the basis of market value of water have been notably unsuccessful. The cost of impoundment is typically a very small part of the costs of providing water service experienced by a municipal water supply company. Attempts to assign values for water in different uses encounter a wide diversity of uses. For example, household usage alone ranges from drinking water (whose value is immeasurable) to the recreational use of a lawn sprinkler which is turned on, not because the grass needs irrigation, but so that the children can play in it on a hot summer day.

It has been said that the limiting value of works constructed for the improvement of water supply is the maximum amount prudent users would be willing to pay for the improved or augmented service. However, precise measurement of benefits on this basis is difficult, if not impossible. The concept serves to place a ceiling (based on judgment) on the value of storage determined by the "alternative-cost" method.

The Alternative-Cost Doctrine

The 1958 report[19/] of the Subcommittee on Evaluation Standards states: "From an overall public viewpoint, a...water supply development will be economically justified if it provides water to meet expected needs at a cost not greater than the cost of the alternative source that would likely be utilized in the absence of the project." Applied to the problem at hand, the stumbling block in this quotation is the word "source".

In the overall picture, it seems certain that the increasing need for firm water supply in the lower Brazos Basin will first be met by additional impoundments of the runoff within the basin. It is not reasonable to assume that this water would be allowed to escape to the Gulf while other water was imported from, say, the Mississippi River. (This is not to be interpreted as ruling out the possibility of interbasin transfers of water.)

Nevertheless, the alternative-cost principle may be applied. Although there is considered to be no alternative water, there are ways to impound it other than by multiple-purpose projects. Unless

otherwise qualified in what follows, the word "Project" will mean the system of five federal reservoirs, Stillhouse Hollow, Somerville, Millican, North San Gabriel and South San Gabriel. In like manner, the word "Alternate" will refer to a hypothetical system of reservoirs which might, in the absence of the Project, be built for water supply only.

Alternative Plan for Water Supply

Meeting the water needs of the study area will apparently require the impoundment of water on each of the major tributaries of the lower Brazos. From a regional standpoint, no single reservoir can be regarded as an alternate to any other, because all will be needed. Hence the decision to look at all five together. The alternate is comprised of five single-purpose dams, located at the same sites as the Corps projects, each having a firm yield equal to that of the project dam. These sites are not the only possible ones for accomplishing the purpose, and validity of the method does not require that alternative sites be the same as project sites. They have been selected for convenience, because of known physical feasibility, and because detailed information for analysis is readily available.

The Fort Worth District Office of the Corps of Engineers furnished estimates of the cost of construction of each single-purpose dam. Table 9 shows these costs and the corresponding annual costs. The latter include operation, maintenance, amortization and interest, using a period of 50 years and an interest rate of 3 per cent.

Each of the aforementioned annual costs is considered to be the minimum annual benefit from water supply storage at the site, from and after the date on which the site might first be needed in the alternative plan.

Sequence of Construction

Although there is no reasonable doubt that all dams in the system would be needed in less than 50 years, it is equally clear that not all are needed now. For subsequent use, it is necessary to assume a sequence of construction and date of first utilization of each dam in the alternative system. Mathematically, there are 120 possible combinations of the five dams. Trial calculations to establish extremes indicate that a range of combined present values, on the order of 20 per cent, would result from different combinations.

The problem of adopting a schedule of sequence and date of construction involves a number of factors. There is a wide diversity in the sizes of individual reservoirs, with yields ranging from 11 to 226 mgd. As might be expected, the unit cost per thousand gallons of potential yield varies inversely with the capacity.

Table 9

Alternative Costs and Present Value

	Stillhouse Hollow	Somerville	North San Gabriel	Millican	South San Gabriel	Sum or Average
Order of Construction	(1)	(2)	(3)	(4)	(5)	
Yield, mgd	63	34	19	226	11	353
Construction Cost, Single-Purpose Alternative	$12,220,000	$11,220,000	$8,250,000	$27,060,000	$5,860,000	
Annual Capital Cost (50 years @ 3%)	475,000	436,000	321,000	1,053,000	228,000	
Annual O & M Cost	40,000	30,000	38,400	57,000	37,600	
Combined Annual Costs	$515,000	$466,000	$359,400	$1,110,000	$265,600	
Unit Costs, Cents/1,000 gal.	2.24	3.76	5.18	1.35	6.62	
Year of First Need	1960	1964	1968	1970	1987	
Years Until Utilized	0	4	8	10	27	
Present Worth Factor	1.000	0.888	0.789	0.744	0.450	
Present Annual Value	$515,000	$414,000	$284,000	$826,000	$120,000	$2,159,000
Present Benefits in ¢/1,000 gal. yield	2.24	3.34	4.10	1.00	2.99	1.68

The sequence which gives the lowest present (1960) value of all future costs, is that of scheduling dams in decreasing order of unit cost, i.e., from largest to smallest size. However, it is believed that this is not necessarily the sequence most likely to be chosen. Building the largest dam (Millican) first would give the least favorable capacity factor (ratio of actual use to capacity) over the longest period of time.

At the opposite extreme might be a sequence from smallest to largest size. Reference to Table 9 will show that the smallest, South San Gabriel, would yield 11 mgd at a unit cost of 6.62 cents per thousand gallons. It seems likely that this unit cost would be higher than the ceiling which the prudent user, mentioned in the introduction to this chapter, would be willing to pay. The engineer, making today a plan for meeting future water supply needs, would probably feel that it might some day be necessary to pay a price that high. But, more than likely, he would defer that project as long as possible.

To a somewhat lesser degree, the foregoing statements would apply to the North San Gabriel site. There, a reservoir to yield 19 mgd would cost 5.18 cents per 1,000 gallons. However, at this point, another facet of the problem should be considered.

A decision to defer construction of the dam on any one of the tributaries would involve the question of present need in the area immediately downstream on that tributary. Detailed study of all such local areas has not been completed at this writing. Local areas which have been investigated are Georgetown and Taylor on the San Gabriel, and Bryan-College Station and Navasota for the Navasota River. The present, and probable future, needs of Georgetown and Navasota can be met by ground water. Estimates of relative transmission costs indicate that Bryan-College Station could obtain water more economically from the main stem of the Brazos than from the Navasota River.

This leaves the Taylor area, in which the ground water is too highly mineralized for satisfactory use. This poses a problem for Taylor for which no answer is readily apparent, unless storage can be provided in one of the San Gabriel multiple-purpose reservoirs, at a cost substantially lower than the figures of 5 to 7 cents per 1,000 gallons. Otherwise, it is believed that some expedient would be found for meeting the relatively small needs of Taylor which would not require expenditure of several million dollars for a dam. For example, good quality ground water is available (from the Edwards formation) about eleven miles west of the city. Nevertheless, in consideration of the local area needs, especially Taylor, the North San Gabriel project has been inserted in the sequence for construction by 1968.

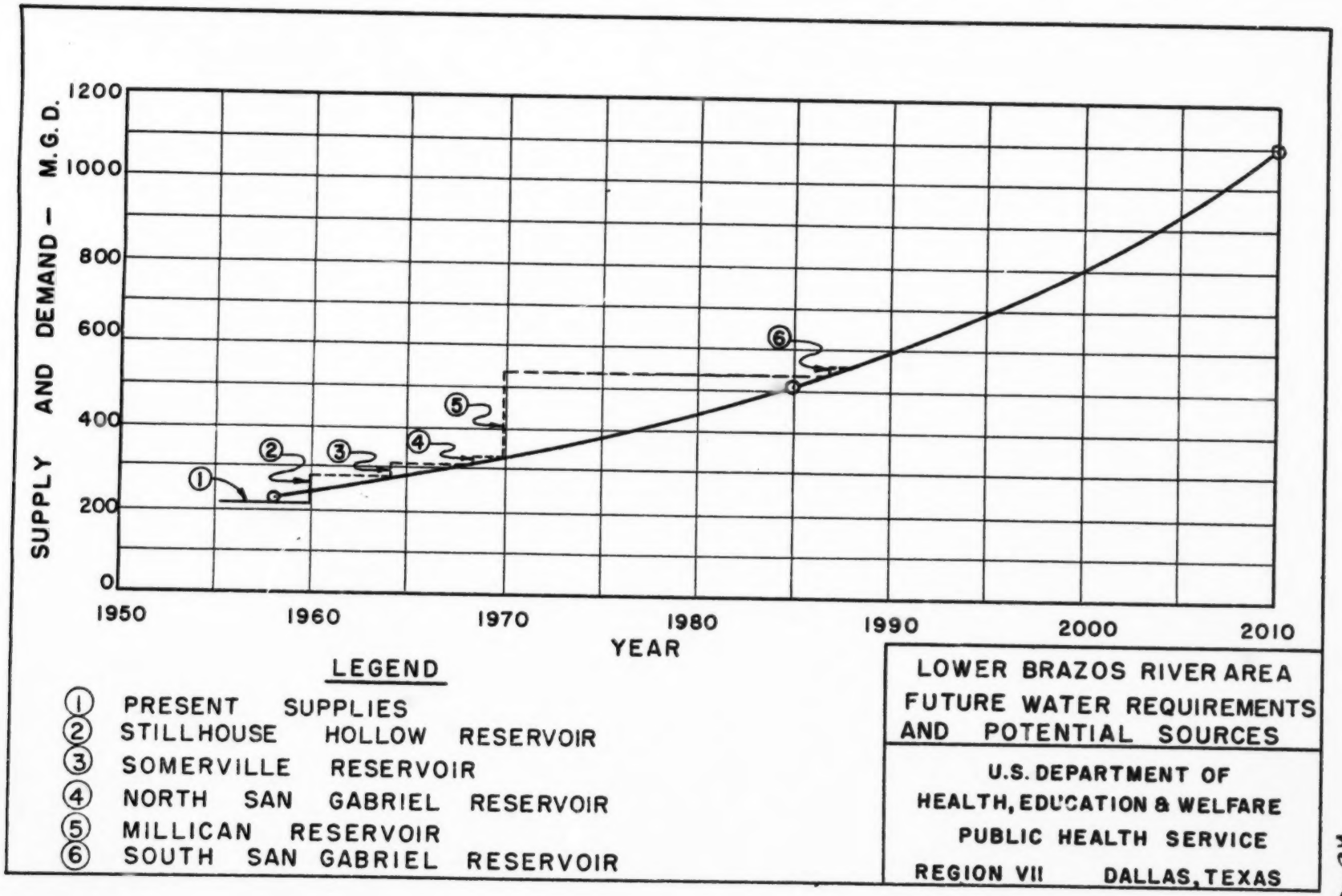
Translation of Alternative Costs to Multiple-Purpose Project Benefits

In spite of complexities and uncertainties, it is essential to formulate an alternative plan for the objective of determining the value of storage in the project. To this end, the sequence of construction of the alternative dams has been assumed to be as indicated in Table 9. The current year (1960) has been selected as the common time base, to which all future benefits are adjusted.

The adjustment of future benefits to present date was made by the method of capitalized costs, as described by Woods and DeGarmo in Introduction to Engineering Economy[20]. Fundamental to the method is the assumption that the physical life of a reservoir (as distinguished from amortization period) is indefinite, but would be longer than 50 years. An interest rate of 3 per cent was used for discounting. Superimposing the yields on a graph of future water requirements, in the adopted sequence, gives the date of first utilization of each reservoir (see Figure 6).

The combined present value of storage in the alternative plan is about 56 million dollars. For a combined yield of 353 mgd, this reduces to a unit value of 1.68 cents per thousand gallons.

It is therefore concluded that the present value (1960) of annual benefits from storage in the several reservoirs of the project will average at least 1.68 cents per thousand gallons of yield. Suggested individual benefits which make up this average are shown in Table 9.


SUPPLY AND DEMAND — M.G.D.
1200
1000
800
600
400
200
0
1950
1960
1970
1980
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①
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⑥
LEGEND
① PRESENT SUPPLIES
② STILLHOUSE HOLLOW RESERVOIR
③ SOMERVILLE RESERVOIR
④ NORTH SAN GABRIEL RESERVOIR
⑤ MILLICAN RESERVOIR
⑥ SOUTH SAN GABRIEL RESERVOIR
LOWER BRAZOS RIVER AREA
FUTURE WATER REQUIREMENTS
AND POTENTIAL SOURCES
U.S. DEPARTMENT OF
HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 6

26a

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